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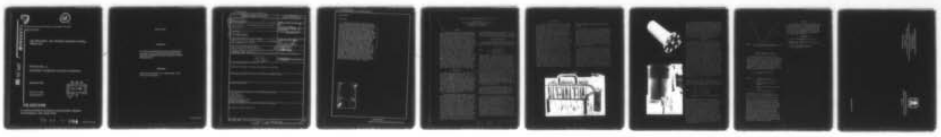

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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LOW INDUCTANCE, LOW IMPEDANCE MEGAWATT AVERAGE POWER LOAD

William Wright, Jr.
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

November 1978

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Abstract:

A compact, low inductance, one-half ohm, one megawatt average power resistive load has been developed to facilitate testing of the MAPS-40 Thyratron. The flowing liquid electrolyte system uses the large thermal mass of a storage tank of electrolyte to store the energy which is dissipated through a heat exchanger after the high power run. The electrolyte starting temperature, flow rate, and allowable temperature rise determine the maximum average power into the load; the external and internal spacings and flow uniformity determine the maximum peak power; and flow rate and storage volume determine maximum running time. The load assembly consists of two parallel glass pipes 10.2 centimeters (cm) in diameter and 15.25 cm long. The active volume in each pipe is 6.35 cm long and is contained between electrodes 8.9 cm in diameter. The two sections of the load are electrically in parallel and flowing in series, putting both flow connections at ground potential. The major problem was getting the internal flow pattern uniform to eliminate local boiling and arcing across the bubbles while keeping the pressure drop low and flow high. The calculated inductance of the load assembly is 11 nanohenry (nH), and the structure lends itself to coaxial connections which reduce the overall inductance still further. Material compatibility with the electrolyte will be discussed.

LOW INDUCTANCE, LOW IMPEDANCE MEGAWATT AVERAGE POWER LOAD

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Summary

A compact, low inductance, one-half ohm, one megawatt average power resistive load has been developed to facilitate testing of the MAPS-40 Thyratron. The flowing liquid electrolyte system uses the large thermal mass of a storage tank of electrolyte to store the energy which is dissipated through a heat exchanger after the high power run. The electrolyte starting temperature, flow rate, and allowable temperature rise determine the maximum average power into the load; the external and internal spacings and flow uniformity determine the maximum peak power; and flow rate and storage volume determine maximum running time. The load assembly consists of two parallel glass pipes 10.2 centimeters (cm) in diameter and 15.25 cm long. The active volume in each pipe is 6.35 cm long and is contained between electrodes 8.9 cm in diameter. The two sections of the load are electrically in parallel and flowing in series, putting both flow connections at ground potential. The major problem was getting the internal flow pattern uniform to eliminate local boiling and arcing across the bubbles while keeping the pressure drop low and flow high. The calculated inductance of the load assembly is 11 nanohenry (nH), and the structure lends itself to coaxial connections which reduce the overall inductance still further. Material compatibility with the electrolyte will be discussed.

Introduction

Liquid electrolyte resistors have been used in experimental modulator setups for many years.[1,2] They offer a wide range in resistance value (at least 5 orders of magnitude), flexibility in physical design, high energy absorption in a compact structure, high voltage stress, and are amenable to low inductance design. They are often easy to design and build, sometimes even trivial, and the resistive medium is forgiving, as opposed to solid resistive substances which are often damaged by overheating or overstressing. Most of the liquid resistor applications have been either single-shot or very low average power where natural cooling is sufficient to dissipate the energy. A liquid resistor for high average power, however, presents some problems.

The load described here was developed to facilitate testing of adiabatic mode modulator components (capacitors, PFN's, thyratrons). The requirements on the load were 20 kilovolt (kV), 10 microsecond (μs) pulse length, 1.0 megawatt (MW) average power, and resistance matched to PFN impedance (0.5 ohm) to within a few percent over the run time of 1 minute. The variation of electrolyte resistivity with temperature (approximately 0.8 percent per degree Celsius (°C) at 30°C), and the requirement of nearly constant resistance would have required and extremely large volume of electrolyte in a noncirculating resistor (over 4000 liters (1)), and a heat exchanger to dissipate the energy during the run would have been impractical, therefore the approach used was to build a circulating load, store the energy in the heated electrolyte and dissipate the heat during the time between runs. This approach uses the difference between the short-term average power (during a run) and long-term average power (over a period of hours) to make the heat exchanging task manageable. The system never reaches thermal stability during a series of runs but is always either heating up or cooling down.

Design Considerations

The electrical energy is deposited in the electrolyte between the electrodes in the resistor. The flow, power input, and temperature rise are related by:

$$P = 70.1\, F \Delta T,$$

where P = input power, watts
F = flow, l/min
ΔT = temperature rise, °C

When the average power is high and the peak power is moderate, the exit temperature may safely approach 100°C. However, when the peak power is also high, 800 MW in this case, high voltage stress and local boiling lead to breakdown across the steam bubbles which could cause the energy to be dissipated in a small volume, rather than uniformly, with explosive forces being generated. For a given input power and flow rate, the exit temperature depends on the entrance temperature, which is the temperature of the electrolyte in the storage tank after the cool-down cycle. For effective heat exchanging, one would like the final electrolyte temperature after cooling to be high, but for an adequate safety factor in avoiding local boiling, this temperature should be low. The required volume of electrolyte must be enough to supply cool electrolyte to the resistor for the duration of the run, allowing for a warm zone in the storage tank where the returning hot electrolyte mixes with the cool electrolyte. This warm zone can be minimized by paying attention to the flow pattern of the electrolyte return.

One of the major advantages of working in this thermal transient mode is that the rate of final energy disposal, heated city water down the drain in this case, depends only on the long-term average power, and the heat exchanger can be minimized consistent with the number of runs desired per day.

In the design of a low impedance load, one important factor is the minimum value of electrolyte resistivity. While others have used sodium chloride, nickel chloride, ammonium chloride, potassium dichromate, sodium thiosulfate, and probably a host of others, I have found that copper sulfate and sulfuric acid in water to be suitable. A concentration of 60 grams (g) hydrous copper sulfate ($CuSO_4 \cdot 5H_2O$, blue) per liter of water gives a resistivity of 70 ohm-cm at room temperautre and is about a factor of 5 away from saturation, which ensures easy dissolving, and no problems with the solute coming out of solution. The resistivity is then adjusted to the desired value by adding small amounts of concentrated sulfuric acid: about 1 percent reduces the resistivity to 12 ohm-cm.

Detailed Design

The load assembly, shown in Figure 1, consists of two resistors, electrically in parallel but flowing in series. This puts both hose connections at ground potential and prevents current flow through the electrolyte filled hoses. Each resistor is a 10.2 cm diameter, 15.25 cm long pyrex glass pipe containing two identical electrode assemblies, and both pipes are contained between two copper plates, 43.2 x 21.6 x 0.635 cm. Each electrode assembly, one of which is shown in Figure 2, is a 8.9 cm diameter by 0.95 cm thick disc on the end of a 5.1 cm diameter copper pipe. There are eight slots, each 0.95 x 2.86 cm, in the pipe behind the electrode and nine 1.25 cm diameter holes in the disc, one in the center, and one adjacent to each slot. The electrolyte flows out through the slots and divides, part through the eight holes and part through the annular gap between the disc and the glass wall. Another part of the flow is directly out through the hole in the center of the disc. The purpose of these holes and slots is to uniformly replace the heated electrolyte with cool electrolyte. In one of the previous designs, with only a large center hole, there was sparking in the electrolyte between the electrodes and near the glass wall at 800 MW peak and 1 MW average power, but not at 800 MW peak and low average power. Presumably the energy was being uniformly deposited in the electrolyte but the heated electrolyte near the walls was not being swept out by the flow, was boiling locally, and the high voltage stress was causing arcing across the steam bubbles. The calculated exit temperature, based on average temperature rise, was only 70°C. No such arcing has been seen with the slotted electrode assembly.

The glass pipes are staybolt clamped between the copper plates by a circle of eight tapped lucite rods around each pipe and sealed with neoprene gaskets which allow for a slight difference in length between the pipes. All assembly between copper pipe, copper plate, and brass disc is with lead-tin soft solder, and a reinforcing ring is used around the lower pipe to which the heavy hoses are attached. Soft solder joints have been suitable for over two years of exposure to this electrolyte mixture, but silver-solder joints eroded in a few weeks. There has been no appreciable erosion of the brass electrodes by the electrolyte.

The circulation system shown in Figure 3, uses a 750 l, 91 cm diameter, 122 cm deep polyethylene tank nearly filled with electrolyte, a 3 horsepower (hp) magnetic drive pump (March Pump, #TE-8C-MD), 5.1 cm reinforced PVC hose, and nylon or PVC plumbing fittings. The cool electrolyte is drawn from the bottom, perpendicular to the side of the tank, and the hot electrolyte is returned to the top, tangent to the circumference of the tank at two places to impart a circular flow. The flow rate is 435 l/min, which corresponds to a temperature rise of 33°C at 1.0 MW average power, and provides 80 seconds of cool electrolyte. This has not been verified because other modulator components have limited run times.

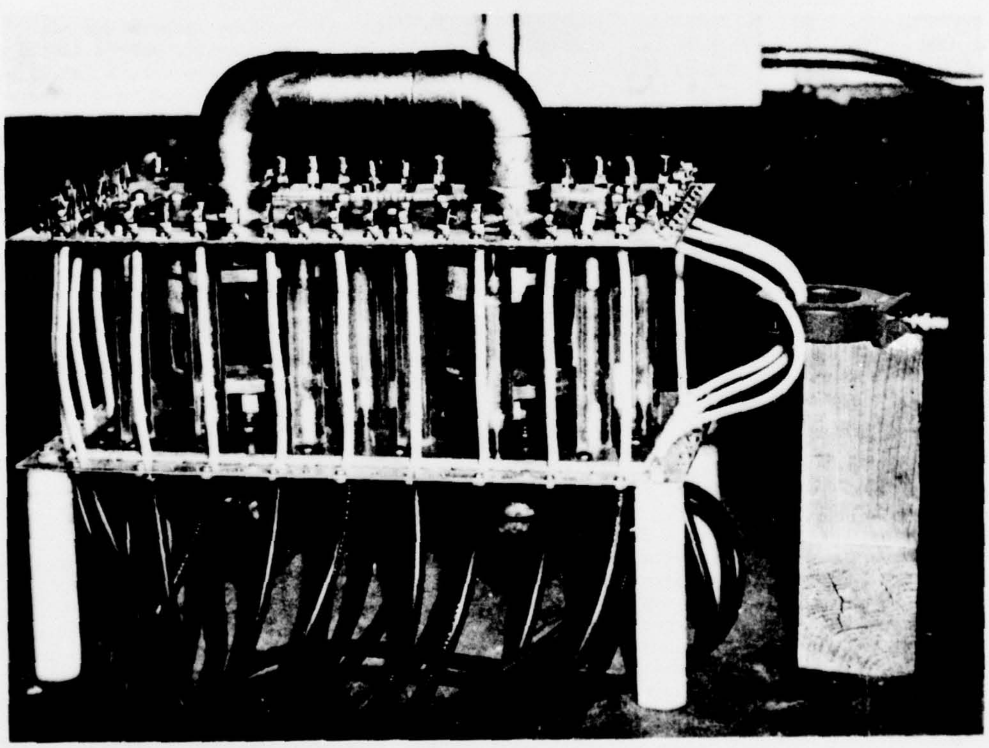

Figure 1. Load Assembly

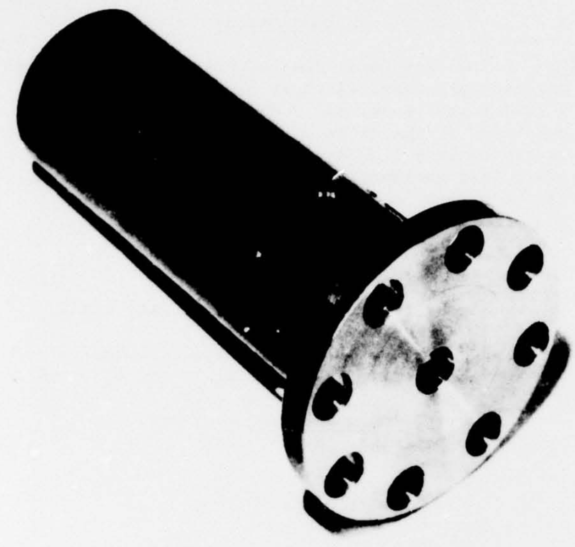

Figure 2. Electrode Assembly

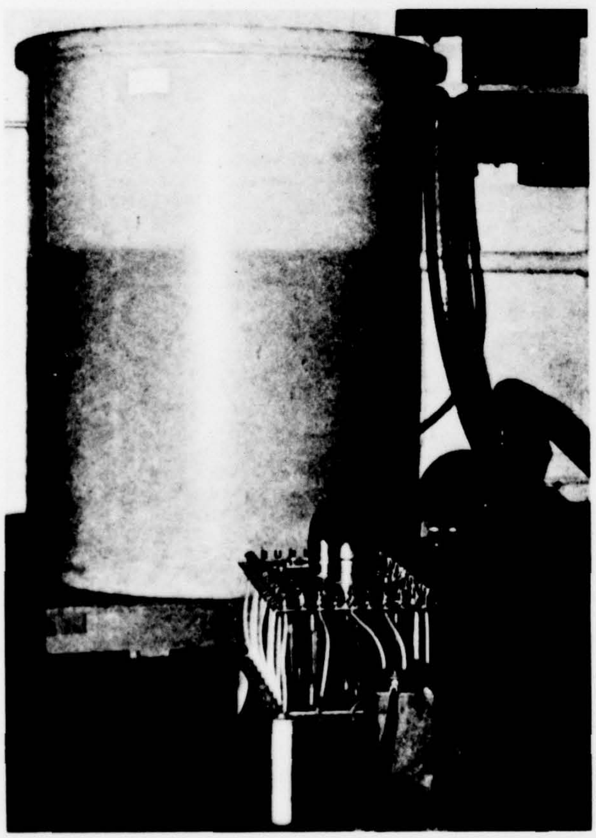

Figure 3. Circulation System

In the present application there was no requirement for closely spaced runs, the long-term average power was low, and a very simple heat exchanger could be used. Fifteen meters of 1.25 cm copper tubing was formed into a 6-coil helix, 76 cm in diameter, 61 cm high and suspended in the tank with 7.6 cm between the tank walls and the coils. The circular flow aids the transfer of heat from the electrolyte to the tap water in the coils, giving a U factor of 410 BTU/hr/sq ft/°F (837 joules/hr/cm^2/°C), and average heat removal rate of 30 kW for water flow of 18.9ℓ/min and electrolyte temperature of 50°C.

Inductance

In general, to minimize inductance one would like to maximize the length of the magnetic flux linkages created by current through a component and minimize the volume in which these linkages exist. This is normally accomplished by making a component as compact as possible, consistent with voltage breakdown, using wide or large diameter conductors, and using coaxial geometry where possible for inductance cancellation. This load can be viewed as a distorted coaxial structure where the outer conductor is an array of 50 conductors (only 25 are being used in Figure 1) evenly spaced around an 43.2 by 21.6 cm rectangle, and the inner conductor is the two paralleled electrolyte-filled glass pipes. Because of the complicated structure, a rigorous calculation of inductance is difficult, but an estimate can be obtained by using the dependence of inductance on the volume of flux-filled space, and hence on area, and the dependence on the length of the flux linkages, or magnetic reluctance, around the space between the conductors, and transforming the actual structure into an easily calculated coaxial cylinder structure with the same area (volume) and the same mean flux linkage circumference. This gives a coax with 35.4 cm outer diameter and 32.5 cm inner diameter. Using the equation for coax with a thin outer and solid inner conductor[3]

$$L = 0.002\ell \quad (\ln r_o/r_i + \frac{1}{4}) \ \mu H$$

gives a value of 10.2 nH. If skin effects pushed the current flow to the outer surface of the inner conductor, the inductance would be 2.6 nH for the same size coax, using the equation for two thin cylinders

$$L = 0.002\ell \quad (\ln r_o/r_i) \ \mu H$$

where ℓ = length of coax structure

r_o = radius of outer cylinder

r_i = radius of inner cylinder, all dimensions in cm.

An experimental determination of inductance can be seen in Figure 4 which shows voltage and current waveforms across the load in a 2 ohm modulator with a 170 nanosecond (ns) pulse width and 87 kA/μs di/dt. The calibration factors have been adjusted to make the amplitudes equal at the peaks where di/dt = 0. Looking at the portion of the curves from maximum positive to maximum negative di/dt, the overlay between voltage and current waveforms shows virtually no inductance. To determine the resolution of the method, voltage waveforms have been calculated for the actual current waveform and an assumed 10 nH and 20 nH inductance in series with the resistor. These waveforms are noticeably displaced from the observed voltage waveform, indicating that the resolution of the technique is better than 10 nH, and the actual inductance is less than 10 nH which agrees with the calculated estimates.

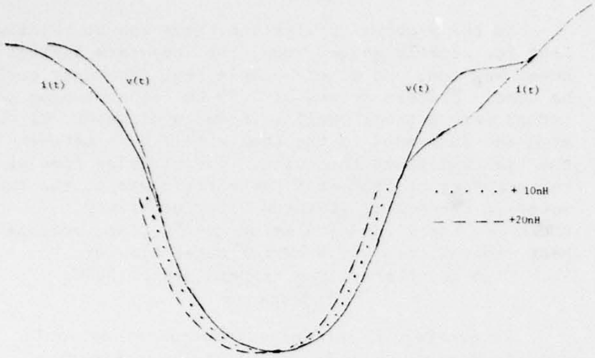

Figure 4. Current and Voltage Waveforms Across Load with Assumed Values of Inductance

Transient Resistance Variation

At the time of the first pulse, with the electrolyte flow already established, all the electrolyte in the resistor is cool. After a short time, which depends on the flow velocity and the physical size of the resistor, the entering electrolyte is cool and the exiting electrolyte is hot; this results in a reduction in resistance. Assuming a linear temperature rise through the active zone of the resistor, and a linear decrease in resistivity with temperature, the stabilized resistance is

$$R = \frac{L}{A}\,\frac{\rho_o^2 - \rho_o\,\alpha\Delta t + 3/16\,(\alpha^2\Delta t^2)}{2\rho_o - \alpha\Delta t}$$

where ρ_o = cold resistivity, ohm-cm

α = change in resistivity, ohm-cm/°C

Δt = temperature rise through load assembly, °C

L = length of active area in one load pipe, cm

A = area of one load pipe, cm^2.

The resistance of the cold load in $L\rho_o/2A$.
For ρ_o = 12 ohm-cm, α = .096 ohm-cm/°C (0.8%/°C), Δt = 33°C, L = 6.35 cm and A = 81 cm^2, R_{hot} = .406 ohm, R_{cold} = .470 ohm; the decrease is 13.6%. Half of the change occurs during the first 71 millisecond (ms) of the run, the time required for the heated electrolyte to cross the active zone in the first glass pipe. There is no change for the next 131 ms while the first heated electrolyte is in the electrode assembly and cross-over pipe. The rest of the variation occurs in the next 71 ms crossing the second glass pipe. After the heated electrolyte reaches the exit pipe equilibrium is established and the resistance is constant for the duration of the run. If the load value were critical, the cold resistance could be adjusted to 13.6 percent higher than the desired stabilized resistance. The structure could be modified to reduce, but not eliminate, the time during which the resistance changes.

Conclusions

A low-impedance, low-inductance resistive load has been developed which is capable of handling a gigawatt peak power and a MW of average power for run times in the order of 60 seconds. The energy is stored in a liquid electrolyte and dissipated via a heat exchanger between runs. The resistance can be a least as low as one-half ohm and the inductance is less than 10 nH.

References

1. W. Nosch, Electrotechnik, 9 (6) 214, 1955.

2. Bishop, et al, "Plasma Physics," Journal of Nuclear Energy, Part C, Vol. 7, pp. 423, 1965.

3. F. Grover, Inductance Calculations, D. Van Nostrand, pp. 41, 1946.

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